COLORADO SPRINGS WATER SYSTEM

REPORT *of*

GEORGE G. ANDERSON

Consulting Engineer

1916

REPORT *on the*

COLORADO SPRINGS WATER SYSTEM

ITS RESOURCES *and* NEEDS

By
GEORGE G. ANDERSON
Consulting Engineer

ISSUED BY THE
WATER DEPARTMENT OF THE CITY OF COLORADO SPRINGS
1916

City of Colorado Springs Water Works

(Letter of Transmittal)

COLORADO SPRINGS, COLORADO,
December 12, 1916.

Hon. C. L. McKesson, Mayor,
Colorado Springs, Colo.

DEAR SIR:

I beg to transmit your herewith my report on the water works system of the City of Colorado Springs, following an extended investigation into all the features which affect it, in its present condition and in its future development.

Extended detail has been unavoidable—it has been the effort to confine such, largely, to the numerous exhibits which accompany and are made a part of this report.

At the conclusion of my work, I desire to thank you for the facilities fully provided me in the examination and in the preparation of this report, and to acknowledge my obligations to Mr. B. B. McReynolds, Superintendent, the benefit of whose intimate knowledge and experience with the system has been fully at my disposal and has been of valuable assistance.

Yours very respectfully,

GEORGE G. ANDERSON,
Consulting Engineer.

Report on the Water Works System of the City of Colorado Springs

The problem presented by the investigation of the water works system of the City of Colorado Springs is the development, along efficient and economical lines, of a plant that, fundamentally, contains within itself all the elements necessary to furnishing pure, wholesome water, in adequate quantities for the needs, not only of the present, but also of a greatly increased population.

Clear realization of the water resources of the system is essential at the outset.

The value, in productive capacity, of the water rights owned by the City, conserved and regulated by the chain of mountain storage reservoirs, cannot be fully comprehended without detailed consideration of the stream flows and the effect upon them of reservoir operation.

In the recurrence of periods in which the service within the City has been insufficient to supply the extreme demands for all purposes, especially for the irrigation of lawns, the distinction between "supply" and "service" has, probably, been overlooked; and all deficiency attributed to the water resources.

As these form the foundation of the whole system, the examination of all elements affecting them has been minute and extensive. The definite conclusions formed upon that feature are the basis of the schemes of development herein submitted, and, as such, will be presented as clearly and concisely as their various details will permit.

The present total operative capacity of the mountain reservoirs is 2,020,000,000 gallons. At the average rate of consumption which has prevailed for the past eight years and which has not materially altered in that time, that storage capacity is sufficient for the needs of the City for a period of 302 days, or ten months, *if all other sources drawn upon by the City failed to furnish any supply.*

During the period of extreme demand in the present year, 1916, the least quantity in storage in the mountain reservoirs was 1,460,000,000 gallons, at the end of April. That quantity was, by itself, sufficient for all the needs of the City, on its present average consumption, for 218 days—more than seven months—*if all other sources had furnished no water during that time.* And that quantity of 1,460,000,000 gallons was the least amount so held in reserve for three years preceding.

The least quantity in reserve, since records have been maintained, with the exception of the first month, occurred in April, 1912, when 872,000,000 gallons were in storage, equal to the demands, on the average consumption, for 130 days—over four months.

After a thorough and painstaking investigation of all the records of stream flow available, a forecast has been made of the relation of consumption to supply. Assumptions have been made (*a*) that the stream flow recorded from 1908 to 1916, inclusive, would repeat in the following period of nine years; (*b*) that the demand would be for a population of 50,000, on the present rate of consumption, distributed throughout the year as it now is.

On these assumptions, the forecast shows that the supply, with the reservoirs in their present operative capacity, would have met the demand throughout the period of nine years, with the exception of some intervals, the most severe of which developed in eighteen separate months, spread over three years.

The lowest rate of supply, depending only on the yield of the direct stream flow when the reservoirs would have been empty, would have been 80 and 82 gallons per capita per day in place of 200 gallons, the present rate of consumption.

Reservoir No. 4, on Beaver Creek, has a capacity of 227,000,000 gallons more than that to which it can now be safely operated. With the necessary repairs made, that addition to the storage would have avoided all shortage in one of the three years mentioned.

It is possible to increase the storage capacity, by creating four additional reservoirs, with a combined capacity of 344,000,000 gallons, approximately. That additional quantity would have avoided the shortage in another year, and would have reduced the shortage in the third year.

A reduction of 5 per cent. in the present rate of consumption, from 200 to 190 gallons per capita per day, would have entirely eliminated all shortage, without any addition to the present storage capacity. The average consumption in 1915 was 186 gallons per capita per day.

For the present population, at the present rate of consumption, the present water resources of the City are entirely adequate. With stream flows in the succeeding years as they have been recorded in the past nine years, which have included three seasons of low flow, and two of high flow, demands would be fully supplied and large reserves carried over.

The same adequate service would be rendered a population of 50,000 or more, by the development of the system, either by increase of storage or decrease in per capita consumption, or both.

The best and most economical development will be secured by the reduction in the rate of consumption. That can be accomplished without hardship or loss to the community, with, on the contrary, the conservation of its resources, and their application to extended areas and to increased population.

Some reduction in per capita consumption will naturally follow from the gradual increase of population.

Reduction in consumption will also follow upon the correction of existing conditions that prevent a sufficient supply for irrigation during extreme drouth. That will not be immediate; it is probable that previous maximum consumption did not reach the limit, from inability to secure the full demand. With an adequate service thoroughly assured, with the knowledge that it may be obtained when needed, the rate of consumption will decrease.

Reduction in the present rate of consumption can be secured by the more extended application of the irrigation ditches, especially the El Paso Canal, owned by the City, to the irrigation of lawns. By such extension, the burden on the domestic service, naturally the more expensive, would be measurably relieved and there would be improved utilization of an important asset of the City—the irrigation ditches and their water rights.

The most material reduction in consumption will come, however, from the installation of meters throughout the City. That alteration in service is inevitable—it is in the interest of efficiency and economy and of the conservation of the property of the City, in which the individual, as part of the community, will share. It will not involve individual loss or hardship, and it is essentially just. It does not involve the reduction of water supply below what is requisite and necessary and, consequently, does not imply that present resources are inadequate. Even if it did, it might be, in this instance, it would be, the most economical method of assuring the adequacy of the water resources.

In the development of the existing water resources, the system now possesses some important advantages. The possibility of creating four new reservoirs of moderate individual capacity has been referred to. The City also owns some rights in the Crater Reservoir Sites, and on what is generally termed the "North Slope."

From the investigation made of stream flow, the conclusion is that it is not necessary, at present, nor when the City has a population 50 per cent. greater than at the present time, even if consumption should then be at the present high rate, to develop these rights, so far as the needs of the population are concerned. It might then be advisable to do so, and, even then, not until the more economical development of reduced consumption had been made. In the meantime, as the reservoir sites and water rights are in the City's ownership and use, they are held in reserve until actually needed.

For the present, and for a considerable time in the future, the resources are adequate, calling only for development when required.

In such development, it may be desirable and prudent for the City to acquire additional water rights, to avoid conflict or possible litigation or for other tactical reasons. In negotiations for any such acquisitions, the assured adequacy of the present resources places the City in a position of superior advantage in resisting undue inflation in water right prices.

With ample water supply in reserve, the existing system becomes defective about the point of leaving the mountains. The pipe system feeding the distribution reservoirs is inadequate; a greater capacity is required in the distribution reservoirs, and the distributing system in the City calls for radical improvement

An additional supply main to the High Line Reservoir is essential; enlargement of that reservoir by, or the construction of a new distribution reservoir, in its vicinity, of at least 10,000,000 gallons capacity is equally so,

and the construction of another distribution reservoir of similar capacity, on the northeast limits of the City is desirable; an additional main of large capacity from the High Line Reservoir to approximately the center of the City, with two main arteries leading from it, easterly and southerly, is necessary, and numerous replacements of and additions to small mains, throughout the system, to complete a "gridiron" for circulation, must be made to secure full service and maintain fire pressures, with some increase in the number of hydrants.

With the purpose not only of increasing the service rendered by the El Paso Canal in the irrigation throughout the City, but also of improving its general condition and effecting its material enhancement as a City property, a plan for its improvement will be outlined.

With these prefatory remarks as a general forecast of this report, it is the purpose to consider each of the features of the system in such detail as their importance warrants, and as may be necessary for clear presentation.

The first and most vital consideration in the investigation of a water supply for the domestic needs of a City is the adequacy of the water resources, not only for the existing population, but for what may reasonably be expected in the immediate future.

In the arid region, where water is scarce and increasingly valuable, it is imperative that water rights affording reliability and sufficiency of supply must be provided well in advance of actual requirements. What the actual requirements may be are dependent upon the probable growth of the population, and upon that, in this and in other situations, there is not too much reliable information available.

Population and Water Consumption

The estimated total population of the City, in which is included Colorado City, has been stated in the reports of the Water Department, since 1912, as 35,000.

The United States Census of 1910 gave the population of Colorado Springs as 29,078, showing an increase of 7,994 since 1910. Colorado City adds approximately 3,000 to the total.

There is no indication that the increase of population in the City is in excess of the normal growth.

The tap register shows only a steady growth, as follows:

Prior to 1907	10,822 taps
At end of 1908	11,202 taps
At end of 1912	11,858 taps
At end of 1913	11,946 taps
At end of 1914	12,024 taps
At end of 1915	12,091 taps

An increase of 1,269 since 1907, indicating a probable growth of from 3,000 to 4,000 inhabitants.

The table of mean monthly consumption shows no material fluctuation in the annual amounts from year to year from May, 1909, to the present date, and only such monthly differences as would be accounted for by differing climatic conditions.

From 1911 to date, the average daily consumption has kept within a range of 600,000 gallons in a total of over 6,700,000 gallons, a variation of less than 10 per cent. That is more clearly shown in the annual statement of consumption per capita per day, as follows:

1909	192 gallons
1910	225 gallons
1911	205 gallons
1912	195 gallons
1913	203 gallons
1914	193 gallons
1915	186 gallons

The higher rates are in years of less than normal rainfall, especially 1911 and 1913, and the lower rates obtained in 1914 and 1915 may be due solely to the greater precipitation in those years.

There is practically no information available to aid the judgment in making an estimate of the future growth of the population. There is nothing to indicate any sudden or rapid increase. The City will always attract tourists, and an assured water supply will tend to increase the number of them, but from that source alone rapid increase cannot be expected. Increased activity in the mining industry is more likely to swell the population than any other cause, and from that the increase is not liable to be as great in the future as it was in the past.

That the population will reach 50,000 within the next fifteen years may be no more than a guess—but in the absence of all reliable methods of forecasting, it will be used in making provisions for future water supply, as the maximum within that period. And the rate of water consumption will be assumed as that of the present time, practically 200 gallons per capita per day.

That is an excessive rate, due almost wholly to the extensive irrigation of lawns from the domestic supply, and involving, as it does, a profligate use of the resources of the community. Every reasonable effort should be made to reduce it, without imperiling any real interest of the individual or the community, as can be done.

Water Resources for Domestic Supply

The sources of water supply, for domestic use, are Beaver Creek and its various tributaries on the Western Slope, and Ruxton Creek and its tributaries on the Eastern Slope, while Bear Creek on the southwest contributes to the total in the vicinity of the City.

The flow of the various streams has been measured over weirs for periods varying from seven to ten years and record made of the daily depths of discharge over these weirs.

In this investigation, these records have been methodically examined, the recorded depths converted into volume of discharge in cubic feet per second daily and the results compiled in tabular form, for the first time, completing the record and providing a form which can be followed in future records.

The work involved in this compilation has taken considerable time, but has been essential in order to arrive at a safe and conservative estimate of the dependable volume of water obtained from the streams, by virtue of the water rights owned by the City, upon which the adequacy of these resources, for the present, and for the future, can be judged.

These stream discharges accompany this report, and are as follows:

Western Slope

Exhibit 7.—Boehmer Creek from July, 1909, to date, daily.
Exhibit 8.—Little Beaver Creek from July, 1909, to date, daily.
Exhibit 9.—Sackett Creek from July, 1909, to date, daily.
Exhibit 10.—Volumes sent to Victor from August, 1909, to date, daily.
Exhibit 11.—Summary of yields of Western Slope streams from July, 1909, to date, monthly.

Eastern Slope

Exhibit 12.—Discharge of Lake Moraine from June, 1908, to date, daily.
Exhibit 13.—Yield of Lake Moraine drainage area from June, 1908, to date, monthly.
Exhibit 14.—Main Ruxton Creek from June, 1908, to date, daily.
Exhibit 15.—Yield of Main Ruxton Creek drainage area from June, 1908, to date, monthly.
Exhibit 16.—South Ruxton Creek from June, 1906, to date, daily.
Exhibit 17.—Sheep Creek from April, 1908, to date, daily.
Exhibit 18.—Lion Creek from April, 1908, to date, daily.
Exhibit 19.—Cabin Creek from August, 1906, to date, daily.
Exhibit 20.—Bear Creek from April, 1908, to date, monthly.
Exhibit 21.—Summary of Eastern Slope Supplies from June, 1906, to date, monthly.

Exhibit 11 shows the summary of all the yield of the Western Slope streams, Beaver Creek and its tributaries, above Reservoir 4 on that stream. The discharges recorded are net flows, and are less than the actual discharge of the streams by the amount of evaporation loss in the reservoirs located up-stream, that is, Reservoirs 7, 8 and 2.

Exhibit 12 shows the discharges from Lake Moraine. That record involves a complex situation, as the discharge at Lake Moraine may include water sent through the St. John Tunnel from the Western Slope and the run-off from the Lake Moraine drainage area, or both of these quantities may be stored in Lake Moraine, in whole or in part.

It has been necessary, therefore, to estimate the run-off from the Lake Moraine drainings area by itself. To do so, the total yield of the Western Slope above Reservoir No. 4 has been taken, the proper credit given to the increase or decrease of storage in Reservoirs 4 and 5, and the amount of seepage loss below these reservoirs, as these items affect that quantity of water sent from the Western Slope, and the increase or decrease of storage in Lake Moraine itself. The proper allowance made for these items, compared with the discharge at Lake Moraine itself, gives the run-off, or an approximation of it, at least, from the drainage area above Lake Moraine. It is inevitable that, with the limited number of measuring weirs and the varying character of the elements involved, the quantities shown in Exhibit 13, as the yield of the Lake Moraine drainage area, will not wholly accord with the actual yield. It is confidently concluded that they are throughout below the actual yield, as comparison of the run-off per square mile with that from adjacent drainage areas, as South Ruxton Creek and Lion Creek show, and that conclusions of total yield of the water resources based upon them will err upon the low side.

It will be obvious, from the above remarks, that all evaporation loss on Reservoirs 4 and 5 and Lake Moraine, and seepage loss below Reservoirs 4 and 5, are included in these quantities of discharge, as they are on the Western Slope streams, above Reservoir 4. As a consequence, the stream flows recorded are less than the actual discharge throughout, and, in all subsequent estimates on the yield and operation of the water resources, the evaporation loss on the various reservoirs is automatically provided for.

The quantities shown on Exhibit 14, Main Ruxton Creek, are the discharges passing over the weir on that creek, including any water passing over the weir at Lake Moraine. Deduction of such quantities must be made, in order to determine the run-off from the Main Ruxton Creek itself, and the result of that is shown in monthly means on Exhibit 15.

In Exhibit 20, Bear Creek Discharges, the quantities shown are the actual diversions into the City pipe system.

The quantity of water obtainable from the yield of the Western Slope streams has been determined by analysis of the stream flows in relation to the rights of priority owned by the City, and is as set forth in Exhibit 11. They are governed, so far as the down-stream priorities are concerned, by an agreement providing that the City shall have the first right to six cubic feet per second, and that, when the Beaver Company is in immediate need of water, to two-thirds of the total run-off of the stream, in excess of six feet, and, so far as the up-stream rights are concerned, by a decree of Court, which provides that the City of Victor shall receive three-quarters of a cubic foot per second whenever the total stream flow above the Strickler

Tunnel is in excess of two and one-half cubic feet per second and there is less than 150,000,000 gallons in the Victor Reservoir..

In preparing Exhibit 11, it was not possible to determine, or to estimate, when the down-stream rights were in immediate need of water, or when the Victor Reservoir would have stored 150,000,000 gallons. One-third of the excess over six cubic feet per second, and three-quarters of a cubic foot per second were deducted from the stream flows, whenever these were in excess of six and two and one-half cubic feet per second, respectively.

The City's share, as shown in the various tables of Exhibit 11, are thus conservative quantities, well within what would actually be secured.

In preparing the tables comprised in Exhibit 21, summary of Eastern Slope supplies, similar care has been exercised to employ quantities that are dependable, and, if at all, below the actual discharges.

As has already been mentioned, the quantities representing the run-off from the drainage areas above Lake Moraine and Main Ruxton Creek are undoubtedly low for the reasons already given.

All other quantities are those actually recorded as the weir discharges, except where noted in the years 1908 and 1909.

It was desirable to have the available supply during the year 1908 included in any estimate or forecast of the water resources, as that year was one of drouth, and below normal precipitation (see Exhibit 5), and also below normal run-off.

From the complete records on South Ruxton and Cabin Creek, and comparison of the relative drainage areas and study of the precipitation records of that year, the missing monthly mean discharges have been estimated. It has been the endeavor to rely solely on records—this slight deviation may be justified for the purpose stated.

The two Exhibits, 11 and 21, thus include the monthly mean quantities, built up from the daily records, available to the City under its water rights, on the Western and Eastern Slopes, from 1908 to the present time in 1916—a period of nine years.

During that period there has been wide variation in all the conditions affecting stream flow. There have been three years of low run-off—1908, 1911, 1913—and the present year may be added to that class, and there have been two years of high run-off—1914 and 1915. Nineteen hundred and fourteen, following the great snowfall of December, 1913, would, presumably, have given the greatest run-off in many years, yet that of 1915 closely approximates it. The precipitation of 1914, at Lake Moraine, has been exceeded three times since 1895, while that at Colorado Springs was the highest for forty years.

It would be desirable to have actual discharge records covering a longer period, but it is believed that these nine years show the extreme conditions, which are liable to recur, and that estimates based upon the records will be dependable and conservative.

Founded upon these two Exhibits, 11 and 21, a forecast is made in Exhibit 22 of the net yield of water sources in relation to the demand of a population of 50,000 on the present rate of consumption.

Beginning as from the end of this year—1916—it is assumed that the succeeding years will yield water supply as they have done in the past nine years. That is to say, the supply secured in 1908 is taken as that which will be secured in 1917, and so on through the succeeding years, up to and including 1925. The schedule is thereby immediately subjected to a severe test, as the first year applied (1908) was that of lowest yield in nine years.

The yields from the Eastern and Western Slopes are separately shown and their total set down against the demand from 50,000, applied, rigidly, on the basis of 200 gallons per capita per day, distributed throughout the various months on the rates developed on the existing conditions as shown in Exhibit 6. The difference between the total yield and the total demand in each month shows the quantity which would be drawn from storage, if yield is less than demand, or which would be available for and added to storage, if yield is more than demand, and the difference set down in the respective columns and added to or deducted from the storage in reservoirs at the end of the preceding month. The amount of storage held in reservoirs beginning the table is the quantity in reserve on December 31, 1916, estimated from the quantity so in reserve on October 31, 1916.

As has been previously stated, no account of evaporation loss has been taken in the tables comprising Exhibit 22, as an equivalent loss has already been made good out of the yields which are used in the tables.

Beginning with January, 1917; full supply continued up to the end of March, 1918, when the reservoirs would be depleted. During April, 1918, there would have been a shortage of 102,000,000 gallons, but the net yield would have provided 130 gallons per capita per day. From May 1, 1918, to April 1, 1920, a full supply continues. Shortages then occur in the succeeding three years, in eighteen separate months when the lowest supply from the net yield of the City's rights would have been 82 gallons per capita per day.

It has been previously stated, but will bear repetition, that the additional capacity of Reservoir No. 4, when repaired, would have obviated the first and practically the second shortage.

Four additional reservoirs could be created within the City's property. One, on Beaver Creek, would have a capacity of 144,000,000 gallons at an estimated cost of about $75,000. The other three are located on the Ruxton Creeks, east of Lake Moraine; have recently been roughly surveyed and are estimated to have a combined capacity of 200,000,000 gallons, approximately, and may involve an expenditure of from $175,000 to $200,000.

The combined capacity of these four reservoirs would have avoided the remaining shortage in the second year and lessened that of the third year.

The reduction of five per cent. in the present rate of consumption, from 200 to 190 gallons per capita per day, would have entirely avoided all shortage; upon the lower rate of consumption, the demands of 50,000 people would have been met continuously.

The consumption rate has been nearly 190 gallons per capita per day in four years out of the preceding seven.

In 1909.....192 gallons
In 1912.....195 gallons
In 1914.....193 gallons
In 1915.....186 gallons

That reduction of five per cent. would have totaled, prior to the first shortage shown, practically 639,000,000 gallons. Such a saving, and more, could reasonably be secured by the installation of meters and on all existing services that might involve a total cost of $125,000 to $150,000.

The four reservoirs would add a capacity of 344,000,000 gallons, at a cost of from $250,000 to $275,000. That is to say, the construction of reservoirs would have provided one-half of the increase in resources produced from part of the saving on meter installation, at twice the cost.

For the present population, at the present rate of consumption, the present water resources of the City are entirely adequate. It is not necessary to submit a schedule forecasting the conditions on such a basis, after what has been shown of the results for a population of 50,000.

For the latter or a larger population, the present resources are also adequate upon the development of the system, on sound business lines, either by the increase of storage or the decrease of per capita consumption, or both. Between the two, there can be no hesitation in the choice, from financial and economic considerations, on the figures above submitted. The determination must be based upon business considerations. The result can be obtained through reduction of consumption, by less expenditure, by real economy, and by the conservation of the resources of the community.

It is desirable to have additional reservoirs east of Lake Moraine, partly because Ruxton Creek and its tributaries occasionally afford excess water available for storage, and partly because the stored supply is brought nearer the point of distribution.

There would be some advantage in an additional reservoir on Beaver Creek, especially above Reservoirs 4 and 5, where seepage loss is heavy (about which there is more to be said) for the better conservation of storable supply above the point of diversion.

From the summary of the Western Slope supply, in Exhibit 11, it is plain, however, that the average yield under the City's rights rarely equals the combined present capacity of the reservoirs; the yield is estimated to have exceeded that capacity in only two years out of eight. It is true, of course, that, as the schedules show, an annual filling to full capacity is not essential nor contemplated.

With these and with the other rights owned by the City, in Crater Reservoir sites, and on the "North Slope", the situation is that they are relatively expensive; that they are not now essential, and that the purpose they would serve when additional supply is required, can be more economically secured through other means.

And as these sites and rights are now within the ownership of the City, their development can be postponed until they are required, without imperiling their validity.

Installation of Meters

To what has already been said of the superior economic advantage to be gained by the introduction of meters over any other method of conserving the water resources, there are other reasons for such introduction.

Regardless of the sufficiency of the water supply, the operating department should know from accurate and well-maintained records all of the facts relating to the supply and the consumption of water. With such knowledge, interest is stimulated toward the correction and prevention of waste from all sources, including leakage from mains. In the arid region, where the rights to water are based upon "beneficial use," every means of preventing waste must be adopted.

Meters will reduce needless waste, in the irrigation season and in freezing weather, by prompting use and better care of improved appliances, and will not restrict the necessary and reasonable use of water.

Consumers may pay for what they use, encouraging thrift in the individual, and placing the burden of extravagance directly where it belongs.

Meters will not detract from the commendable effort to beautify the City by the maintenance of lawns. By their use, if the domestic service continues to be burdened with irrigation service, the fact that excess application of water is not essential to the best results will be more readily recognized than in any other way.

And, above all other reasons, the situation before the City of Colorado Springs at the present time is an economic one—to realize the best returns from its resources—and that involves the employment of every means that tend to efficiency, to the full development of the community's property—in the large sense—and that includes the water resources, the adequate supply of water to the consumer and the beautification of the City and its surroundings.

It has been estimated that to connect the existing services, some 12,000 taps, with meters, would cost approximately $150,000—probably less than that.

It is now estimated that a reduction of 25 per cent. in the consumption rate would follow on such installation. On the present average consumption, that reduction of 25 per cent. would mean a saving of over 600,000,000 gallons per annum. That represents a cost of $250 per million gallons of storage. There is no available reservoir site that can be developed at such low cost.

Solely on economic grounds, the installation of meters is in the best interests of the City.

Distribution System

Before commenting upon the physical features of the reservoir system and related structures, consideration of the distribution system, in which the existing defects to be remedied are largely centered, will be taken up.

For the purpose of feeding the main and highest distribution reservoir, the High Line Reservoir, the present 16" main from Adams' Crossing, is of inadequate capacity to assure continuous supply to the portion of the City dependent upon it.

The records of the storage in the High Line Reservoir during the period of maximum demand in the present year show decrease in considerable quantity, indicating that the feeder pipe line was inadequate to supply the draft, which probably was not as much as it would have been with greater available supply and better distribution facilities.

The immediate construction of a 20" pipe line from Adams' Crossing to the High Line Reservoir is essential. With that addition, the delivery from Adams' Crossing will equal the capacity of the 24" main from the Manitou Settling Tank, and will prove adequate, with the other feeder mains, for a population of 50,000.

The capacity of the distribution reservoirs must be increased. At the present time, the combined capacity is 22,879,835 gallons, distributed as follows:

	ELEVATION	DEPTH FEET	AREA ACRES	CAPACITY GALLONS
Mesa No. 1.....	6,211	13	0.32	855,525
Mesa No. 2.....	6,211	15.5	2.68	9,882,422
High Line	6,428	24	5.60	12,141,888
Total.....				22,879,835

On the present average rate of consumption, 6,700,000 gallons per day, the reservoir capacity is equal to a three and one-third days' supply, if for any reason supply from the outside sources should be cut off.

An addition of 20,000,000 gallons to the reservoir capacity should ultimately be made, one-half of which should be located on the west side, at or near the High Line Reservoir, the other half in the vicinity of the northeast limits of the City, on which further comments will be made.

Investigation has been made of various sites possible near the High Line Reservoir, to the elevation of which any new reservoir should approximate. All considerations favor the installation of the new reservoir, within the property of the City, either by constructing an entirely new basin, concrete lined and roofed over, or by the enlargement of the High Line Reservoir.

A concrete-lined, covered reservoir is the more desirable, particularly from the sanitary point of view, but the enlargement of the High Line Reservoir proves to be much the less expensive and is in the natural development of the City's property, while, with ordinary care, its sanitary condition can be thoroughly maintained.

From the High Line Reservoir, on the best available route, preferably along the Mesa Boulevard, a new 18" main of approximately 12,000,000 gallons capacity will be built to the intersection of Cache la Poudre and Walnut street. Its purpose will be to reinforce the main distribution system within the City at about the division between the High and Low services. From it will extend a 16" main across Cache la Poudre to Hancock, and from that a 12" secondary feeder on Wahsatch from Cache la Poudre to Rio Grande, as more fully shown on map and schedule, Exhibit 23.

The main cause of the difficulty to secure a sufficient supply of water during periods of extreme irrigation demand—apart from the excessive quantity of that demand—and the consequent decrease in pressures, as much as 60 pounds in the High and 40 pounds in the Low service, is due to the long lines of small pipe and the insufficient number of cross-connections, "gridironing" the system.

In the residential sections, there are such long lines of 4" pipe, extending from Madison to Uintah between Tejon and Nevada, from Cache la Poudre to Bijou between Cascade and Tejon, and from Cache la Poudre to Huerfano between Weber and Wahsatch, to mention only a few instances, while on Pike's Peak Avenue, from Cascade east to Wahsatch, there is but a single 6" pipe.

A plan of rectification and reinforcement has been prepared, as shown on the map and in the schedule, Exhibit 24, with increase of hydrants as shown on Exhibit 25, all features of which are essential for immediate construction.

The main purpose has been to eliminate all pipes of less than 4" diameter—to replace them by 6" or greater—to provide a complete gridiron and to give effective service, and by it, adequate service will be provided, without material reduction of pressure.

The elimination of pipes less than 6" has not been carried as far as might be desirable, though a total length of about seven miles will be removed. For some districts, such mains will prove adequate; in others, the replacement should be made gradually and as the settlement builds up. Consideration has been given to the local situation, particularly in outlying districts.

As an outlay, as planned, the additions and alterations, with possible modification as work progresses, will meet the requirements of domestic, irrigation and fire protection purposes for some considerable time to come, with the extensions that come under ordinary operation, and, particularly will it so meet the requirements, if the suggestions regarding irrigation service and the rational reduction in consumption herein made are carried into effect.

Reference has been made to the installation of a distribution reservoir of 10,000,000 gallons capacity on the northeast limits of the City.

A suitable location exists, at an elevation approximately that of the Mesa Reservoirs, which would be reached by the extension of the 16" main on the north boundary of the City, for a distance of approximately 3,000 feet, connecting the new reservoir directly with the High Line Reservoir.

Such a reservoir would possess numerous advantages in the extension and development of the City. It would provide additional storage of one and one-half days' supply for the total population and more than that for the consumers reached by it directly.

At the present time, all the feeder pipes for the main portion of the City cross Monument Creek. Accidents and washouts at that crossing are always possible during extreme floods, and while the experience has been that any such accident can be repaired within twenty-four hours, the liability to longer interruption of the service continues. Under the circumstances, a reserve storage is desirable.

Such new reservoir would act as an equalizing or regulating agency and could help maintain service in the High service district, if for any reason it was temporarily reduced.

Finally, its location would command the region to which, in all probability, any extension of the City will naturally be directed, and in that view, its construction would be in the direct line of the natural development of the system.

While construction is not immediately necessary, as the plans for distribution reinforcement are adequate, it should be provided for, and the necessary site acquired, at least.

Physical Condition of Structures

Western Slope

Some repairs of a minor character are needed on the concrete spillway at Reservoir No. 8, at a probable cost of $200.

At the Strickler Tunnel, further lining of the tunnel may be required, though not immediately. About 1,800 feet at the west end of the tunnel is now lined and is in fairly good condition, and the unlined portion is 4,680 feet long. There is known to be leakage on the top in this section, and probably on the bottom. In view of the altitude and location of the tunnel, the cost of repairs will be comparatively high and may reach $60,000.

At the west end of the tunnel the valves regulating the flow of water to Victor are located. It may be advisable to house these to increase the difficulty of interference, though housing by itself will not prevent determined effort to secure access, and may only involve greater cost in repairs.

Reservoir No. 2 is in good repair, save that the top of the masonry at the outlet has been knocked off and the outlet valve become inoperative. As a result, the reservoir has not been drawn upon for several years; it has remained at full capacity. An emergency may arise which would require its operation, and as the expenditure would probably not exceed $250 (including a diving apparatus at $175), the repair should be made immediately.

At Reservoir No. 4, the dam is in seriously defective condition, and as its condition not only materially reduces the storage capacity, but is a constant menace, it should be immediately repaired. The burdens of the operating department should not be increased by constant anxiety over long-neglected defects in an important structure. That the dam was saved from complete disaster was undoubtedly due to the strenuous efforts of the superintendent and the operating force.

Radical improvements are necessary. The whole inner face requires to be puddled for a depth of 25 feet, with a thickness of five feet, and there should be further puddling at the inner toe and in front of the dam itself. The back slope should be increased from one and one-half to one to two and one-half to one, and under its base a complete system of drainage, of rock preferably, installed. Because of that increased slope, the valve house will have to be removed and rebuilt, and additional rip-rap should be placed on the outer toe of the back slope. It has already been stated that the operative capacity is 227,000,000 gallons less than its maximum capacity, to which it is not now safe to impound water.

In view of the indeterminate extent of some of the necessary work, as the puddling at the outer toe, the estimate of repairs must be made large, at $35,000.

Reservoir No. 5 is now in fair condition.

Below Reservoirs 4 and 5 there is a constant seepage loss, varying from 1,500,000 to 2,500,000 gallons daily, the fluctuation differing with the height of water in the reservoirs. There has been some slight reduction in the volume, and the repairs at Reservoir No. 4 will further reduce it, though not in any great degree; 25 per cent. is probably a high estimate.

The larger part of the seepage apparently comes from Reservoir 5, and from the natural hillsides surrounding it, rather than from the artificial dams, though the visible seepage at the dam of Reservoir 4 is quite large.

From the nature of the soil in the adjacent hillsides, relatively heavy seepage loss was inevitable at these reservoirs, and practically unavoidable by any process of blanketing or otherwise within their areas, on account of the cost involved to secure uncertain results.

Any effort to save the seepage and divert it back and up-stream into the system would be difficult and involve prohibitive cost. Various methods have been proposed, including diversion by tunnel to the Eastern Slope, the least expensive of which, $200,000, is at greater unit price, for the seepage saved, than an equivalent volume of water could be secured for by other means, or in the open market for water rights.

It is regrettable that in the original location of these Reservoirs 4 and 5 the topographic advantages of the location were not fully realized. Some distance below both dams there is a site where the construction of one dam, involving less cost than either 4 or 5—certainly of 4—would have impounded all the water of their maximum capacities, and an additional quantity in the area lying between them. The seepage loss would have been sensibly reduced and the dam would have retained part of what now flows down-

stream. And there would have been other advantages which need not now be referred to.

The reference was made for the reason that that dam site is still available. A dam built there now would cover up the dams of Reservoirs 4 and 5 and render unnecessary the pipe system leading to and from Reservoir 5. Such dam might take the place of the repairs to Reservoir 4, though the conclusion is that there is not now available from the stream flow of Beaver Creek sufficient quantities above that now secured to warrant increase of reservoir capacities, except the addition on Reservoir 4.

Reservoirs 8 and 2 could be similarly enlarged, and Reservoir 3 constructed; but it has been already pointed out, as shown by Exhibit 11, that the City's share in the Beaver Creek stream flow would have exceeded the existing reservoir capacity in only two out of eight years.

Construction of the reservoir which should have been built originally is not advised now, and it is not deemed practical to attempt any construction to save the seepage, the amount of which, as has been previously noted, has been deducted from all estimates of dependable yield.

The St. John's Tunnel is, generally, in fair condition. The eastern end is in need of repairs, which should be made in connection with the repairs to the "falls" to Lake Moraine. These are in bad condition. Dropping water down 600 feet on a loose hillside inevitably spells trouble.

It is not business-like to attempt cleaning up the channel. The water should be piped down hill. That might be done by a concrete flume; but in view of the power possibilities, a pipe line is preferable, at an estimated cost of $32,000.

Eastern Slope

Lake Moraine is in fairly good condition.

On account of the large seepage, and the danger from it on the hillsides east of the Lake, it is not operatively advisable to maintain the reservoir at its maximum capacity of 260,000,000 gallons. The water surface is usually kept one foot below spillway level, at capacity of 237,000,000 gallons.

It is not advisable to increase the capacity of Lake Moraine for that reason, and that is especially true regarding the basin at the south end of the Lake. Efforts have previously been made to utilize that basin, when it was found impossible to prevent leakage, and the condition of the hillside east of and below the Lake became menacing. That danger would still exist, because of the character of the soil on that hillside.

Additional reservoir capacity east of Lake Moraine is desirable, for reasons already given. Rough preliminary surveys have been recently made, of which the results have been noted. More detailed surveys should be made to obtain full data for future guidance, even if construction may be remote.

The present wooden structures at the various intakes on Main Ruxton, South Ruxton and Cabin Creek should be replaced by concrete works, at a combined cost of $3,000.

Bear Creek

On this part of the system, a transfer of the point of diversion upstream above the High Drive has become necessary to protect the character of the supply against possible pollution of the stream by the increasing number of picnickers.

On the data furnished by a survey made some years ago, the cost of this alteration would be $25,000. A change of the line from the south side of the stream, as then surveyed, to the north is advisable, for construction reasons mostly, but also to incorporate the stream flow of Hunter's Run in the pipe line and to the better utilization of fall for possible power development. This improvement may be deferred, but from sanitary considerations it is desirable to undertake it soon.

If it should be deferred for any considerable time, the present wooden intake structures should be replaced by concrete, at a cost of $1,000.

Pipe Line from Adams' Crossing to High Line Reservoir

There are several places in this main feeder, and on the main leading from the reservoir to the City, where the pipe (of steel) has been found to be badly pitted and the outer covering being rapidly eaten off. The decay is undoubtedly due to some chemical action in the soils, which are entirely different in character east and west of the Reservoir. In the western section, the resulting leakage has mostly developed in a well-defined area, about 600 feet in length, though there is no assurance that the source of the trouble may not extend for a considerable distance. Extra care and watchfulness is required, and material kept on hand for emergency. The new line, the necessity for which is increased by this weakness in the existing main, will be of cast-iron pipe.

Irrigation Ditches

The irrigation system consists of two main supplies—the El Paso Canal, from Fountain Creek, and the Monument Creek Pipe Line, with which latter two reservoirs are attached, with a combined capacity of over 89,000,000 gallons. The water carried by these ditches is used to irrigate the parks and parkings, in part, and about 520 acres, including about 100 acres of garden tracts, of the area in the City.

Prospect Lake obtains its supply from the surplus water in the domestic system. It is possible to convey water from the Lake back into the City for either irrigation or domestic use; but it is undesirable for the latter, and the cemetery is now irrigated from it. As its surroundings are now a park and camping ground for autoists, its water level should be kept as nearly constant as possible, and consequently extension of irrigation service from it is not advisable.

Originally used for the irrigation of lawns throughout the City, the use of the ditches for that purpose has been almost entirely abandoned, only about 10 per cent. of the area now being supplied from that source. That service has been transferred to the domestic system, increasing its burden

by taxing it with the largest part of the consumption, devoting the best and highest-priced water to a service which can be just as well rendered by low-cost water, and giving up, in the sense of not utilizing to their full capacity, a valuable asset of the City—its irrigation rights.

The use of water for irrigation of lawns is excessive, even admitting that the soil is open and porous and requires large quantities for the desired results.

Objection is entertained to the use of the irrigation ditch water, especially that from the El Paso Canal, because the intake is below the outlet of the Manitou sewers, because the ditches are charged with silt and occasionally carry the seeds of noxious weeds, which injure the appearance of the lawns. These objectionable features can be removed, especially in conjunction with alterations on the line of the canal which are inevitable, and the canal can be developed to perform a larger service and give more adequate return on its real value.

It is physically possible to connect the ditch system with most of the lawns without hardship to the lot owner, which it is desired to avoid It is understood that irrigation service was to be free of charge, but it was probably not intended that such service should be from the highest-priced element in the water system.

The condition of the El Paso Canal, as it passes through Colorado City and that part of Colorado Springs circling the end of the Mesa, in alleys and back yards and across lots, is not only unsightly, but unhealthy, and rapidly becoming a nuisance ground. At no distant date it will be made compulsory to cover it. The City should now anticipate that action, and combine it with other works of improvement.

The site of a settling reservoir can be located on Camp Creek. To connect it with the Fountain Creek, it may be necessary to change the point of diversion of the El Paso Canal up-stream, possibly above the Manitou sewer outlet, or so close to it that the extension of that outlet below the new intake would not entail any great expenditure, either upon Manitou, upon whom the burden doubtless legally rests, or upon Colorado Springs for its own good.

From the settling reservoir the canal could be carried in pipe, in straighter route, through streets and alleys, and avoiding the long detour around the Mesa ridge, cut through the Gravel Pit Hill, with maximum depth of 20 feet, to a connection with the present ditch on the east side of the Mesa. That change would replace 12,000 feet of canal line, would remove an eyesore, greatly improve the service, lessen the cost of operation, and eliminate the features that are objectionable in the irrigation of the lawns in the City.

Similar improvements can be made from the Gravel Pit Hill north to the crossing of Monument Creek; but they may be deferred.

From approximate estimates made without survey, the cost of these improvements would be $40,000.

Field surveys should be made to obtain full data from which close estimates can be made and the betterment given serious consideration.

Cost of Improvements to Distribution System

The detailed estimate of cost of improvements to the distribution system is as follows:

High Line Reservoir	$ 15,000.00
20″ pipe—Adams' Crossing—High Line Reservoir—9,370 feet at $5.50 per lin. ft.	51,535.00
18″ pipe—High Line Reservoir to City—13,200 feet at $5.00 per lin. ft.	66,000.00
16″ pipe on Cache la Poudre—8,800 feet at $4.20 per lin. ft.	36,960.00
12″ pipe on Wahsatch—7,800 feet at $2.70 per lin. ft.	21,060.00
12″ pipe on Pike's Peak Avenue—2,050 feet at $2.70 per lin. ft.	5,535.00
Cutting and replacing pavement on Pike's Peak Avenue	3,300.00
8″ pipe (as per list), 4,200 feet at $1.65 per lin. ft.	6,930.00
6″ pipe (as per list), 51,660 feet at $1.25 per lin. ft.	64,575.00
4″ pipe (as per list), 10,755 feet—replacement work—at 60c per lin. ft.	6,453.00
30 hydrants at $80 each	2,400.00
	$279,748.00
Contingencies and incidentals, say	20,252.00
	$300,000.00

To which should be added the cost of new reservoir on the northeast of the City limits and of the 16″ pipe line connection, at $75,000, which, as has been said, may be deferred.

These estimates are based upon present-day costs of material, which is very high, cast-iron pipe at $47.75 per ton.

In order to avoid a recurrence of insufficient supply during the coming summer, the greater part of this work should be proceeded with immediately. It would be well, indeed, if the work of replacement within the City was under progress at this time.

Summary of Necessary Expenditures

Provision should be made at once for the following amounts:

Western Slope:	
Repairs to Reservoir 4 and others	$ 35,450.00
Lining of Strickler Tunnel	60,000.00
Pipe Line — St. John's Tunnel — Lake Moraine	32,000.00
Eastern Slope: New Intakes	3,000.00
Bear Creek: Change of Line	25,000.00
El Paso Canal	40,000.00
Distribution System	300,000.00
New Reservoir and Pipe Line	75,000.00
Installation of Meters	150,000.00
	$720,450.00

The amount required for minor items, such as the surveys for reservoir sites, as recommended, may be provided for, as now, out of the current operative funds. Additional provision should be made for funds with which to purchase lands needed for the further protection of the watersheds.

Sound judgment must be exercised in deciding upon the order and time in which the various improvements should be undertaken, consideration being duly given to the safety of structures, the urgency of the works in relation to the requirements of the community, and the general economic situation.

Investigation of Other Available Sources of Water Supply

Preliminary investigation was made of all other water sources in the immediate vicinity that might be available for the City.

In view of the definite conclusions arrived at of the adequacy of the present resources, it was not necessary to extend these investigations, or to open negotiations, or to make further comments upon them now.

Consideration has also been given to the rights acquired by the City on the North Slope. As has already been stated, the cost of reservoir construction in that section would be relatively high, in relation to storage capacity, and development should not be undertaken until other and less expensive sources were fully utilized.

The acquisition of lands and water rights, and securing Congressional action in the reservation of public lands, which should be continued, was an exercise of wise and prudent foresight in the interest of the City, providing for the possible needs of an increased population well in advance of actual use.

It will be advisable to maintain gaugings of the streams embraced in the North Slope territory, as is done elsewhere on the Western and Eastern Slopes. It is desirable to have records of the amount of water supply available to the El Paso Canal, of which these North Slope streams supply the major portion; and daily records should also be maintained of the diversions made by the El Paso Canal and the Monument Creek ditch.

Quality of Water for Domestic Use and Measures for Its Protection

The quality of water supplied for domestic use is excellent. The situation of the collection areas of the system is, on the whole, extremely fortunate, and the measures taken for its protection have been progressively well considered.

Control of the watershed area is highly desirable, and that is being steadily secured. The recent purchase of the Half-Way House and the Keith land is a very desirable and necessary acquisition. Further purchases are in contemplation, as conditions warrant, and, as has elsewhere been pointed out, financial provision should be made to permit such purchases in the future, as favorable opportunities present themselves.

Some minor improvements remain to be made. It is advisable to correct the conditions along Lion Creek, by fencing the right of way along the Cog Railroad, piping the various stream crossings, and establishing toilets at directed points, to remain under control of the City. These are necessary to prevent as much as possible the danger of stream pollution by travelers along the trail to the Pike's Peak Summit.

The houses at the west end, near Reservoirs 7 and 8, should be moved to the vicinity of the west end of the Strickler Tunnel and the operating valves there, accomplishing the double purpose of further protecting the water stored in the reservoirs and guarding against interference with the valve operations.

The Lake Moraine houses should also be removed to a location such that drainage could not possibly be directed to the Lake.

The necessity for the transfer of the point of diversion on Bear Creek to a point up-stream above the High Drive has already been mentioned. In view of the large and increasing number of picnickers along the Drive and the danger of pollution from careless acts of such visitors, this change should not be unduly postponed.

The full protection of the collection areas can be best and most readily secured by continued efforts on well-defined policies, which the Department keeps fully in mind.

Conclusion

With the rectifications, and amendments, and improvements herein recommended carried out in their entirety, the water works system of the City of Colorado Springs will be adequate for the needs of its population, at the present time and for a considerable time in the future, and will be on a sound business and economic basis.

It has been the aim to consider all of the aspects of the situation and present the conclusions arrived at, and the reasons thereof, clearly and fully, especially so that the citizens can weigh the business considerations, and in that view one other feature calls for brief comment.

It will be clear that the success of the construction work largely, and of the operative work wholly, depends upon the character of the superintendence, and the obligation implied in the undertaking of this investigation and report would not be fully completed without comment on that feature.

With extended opportunity for contact with the operating departments of similar works, performing the serious and responsible function of supplying the public with water, it must be said, in all earnestness, that the City of Colorado Springs is more fortunate than it evidently realizes in retaining in the office of Superintendent the present incumbent, Mr. B. B. McReynolds. In the close association with and through observation of him, during this examination, not only his extensive knowledge and practical experience of the operation of the present system, but his clear insight into and broad grasp of the problems to be solved, have been made abundantly clear. Mr. McReynolds merits in a singular degree the confidence and support of the citizens and more material recognition of the value of his services.

All of which is duly submitted by

Yours very respectfully,

GEORGE G. ANDERSON,
Consulting Engineer.

December 12, 1916.

NOTE.—Accompanying the foregoing report there are 157 pages of exhibits to which reference is made in the report, and a large map showing the location of all water mains from the Mesa Reservoirs to the city. Also the location of all water mains and pipe lines in the city and the size and location of all mains and pipe lines which the Engineer finds should be laid to give the city an adequate system for the distribution of water. These exhibits and map could not be published without large expense, but they are on file in the City Clerk's office and can be examined by any one interested in them.